



How conflict affects land use agricultural activity in areas seized by the Islamic State

Eklund, Lina; Degerald, Michael; Brandt, Martin Stefan; Prishchepov, Alexander; Pilesjö, Petter

Published in:
Environmental Research Letters

DOI:
[10.1088/1748-9326/aa673a](https://doi.org/10.1088/1748-9326/aa673a)

Publication date:
2017

Document version
Publisher's PDF, also known as Version of record

Document license:
[CC BY](#)

Citation for published version (APA):
Eklund, L., Degerald, M., Brandt, M. S., Prishchepov, A., & Pilesjö, P. (2017). How conflict affects land use: agricultural activity in areas seized by the Islamic State. *Environmental Research Letters*, 12(5), [054004]. <https://doi.org/10.1088/1748-9326/aa673a>

How conflict affects land use: agricultural activity in areas seized by the Islamic State

This content has been downloaded from IOPscience. Please scroll down to see the full text.

2017 Environ. Res. Lett. 12 054004

(<http://iopscience.iop.org/1748-9326/12/5/054004>)

View [the table of contents for this issue](#), or go to the [journal homepage](#) for more

Download details:

IP Address: 130.225.98.216

This content was downloaded on 26/05/2017 at 09:03

Please note that [terms and conditions apply](#).

You may also be interested in:

[Long-term agricultural land-cover change and potential for cropland expansion in the former Virgin Lands area of Kazakhstan](#)

Roland Kraemer, Alexander V Prishchepov, Daniel Müller et al.

[Mapping cropland-use intensity across Europe using MODIS NDVI time series](#)

Stephan Estel, Tobias Kuemmerle, Christian Levers et al.

[Mapping the extent of abandoned farmland in Central and Eastern Europe using MODIS time series satellite data](#)

Camilo Alcantara, Tobias Kuemmerle, Matthias Baumann et al.

[Agricultural land change in the Carpathian ecoregion after the breakdown of socialism and expansion of the European Union](#)

Patrick Griffiths, Daniel Müller, Tobias Kuemmerle et al.

[Hotspots of land use change in Europe](#)

Tobias Kuemmerle, Christian Levers, Karlheinz Erb et al.

[Rapid land use change after socio-economic disturbances: the collapse of the Soviet Union versus Chernobyl](#)

Patrick Hostert, Tobias Kuemmerle, Alexander Prishchepov et al.

[Effects of institutional changes on land use: agricultural land abandonment during the transition from state-command to market-driven economies in post-Soviet Eastern Europe](#)

Alexander V Prishchepov, Volker C Radeloff, Matthias Baumann et al.

[Multiple pathways of commodity crop expansion in tropical forest landscapes](#)

Patrick Meyfroidt, Kimberly M Carlson, Matthew E Fagan et al.

Environmental Research Letters



LETTER

OPEN ACCESS

RECEIVED

30 November 2016

REVISED

9 March 2017

ACCEPTED FOR PUBLICATION

16 March 2017

PUBLISHED

28 April 2017

Original content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](#).

Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.



How conflict affects land use: agricultural activity in areas seized by the Islamic State

Lina Eklund^{1,7}, Michael Degerald², Martin Brandt³, Alexander V Prishchepov^{3,4} and Petter Pilesjö^{1,5,6}

¹ Center for Middle Eastern Studies, Lund University, Finngatan 16, S-223 62 Lund, Sweden

² Interdisciplinary Near and Middle East Studies, University of Washington, Seattle, WA 98105, United States of America

³ Department of Geosciences and Natural Resource Management (IGN), Copenhagen University, Øster Voldgade 10, DK-1350 København, Denmark

⁴ Institute of Environmental Sciences, Kazan Federal University, Kazan, Tovarisheskaya str.5, 420097, Kazan, Russia

⁵ Department of Earth and Ecosystem Sciences, Lund University, Sölvegatan 12, S-22362, Lund, Sweden

⁶ GIS centre, Lund University, Sölvegatan 10, S-22362, Lund, Sweden

⁷ Author to whom any correspondence should be addressed.

E-mail: lina.eklund@cme.lu.se

Keywords: conflict, land use change, land systems, Islamic State, agriculture, cropland

Supplementary material for this article is available [online](#)

Abstract

Socio-economic shocks, technogenic catastrophes, and armed conflicts often have drastic impacts on local and regional food security through disruption of agricultural production and food trade, reduced investments, and deterioration of land and infrastructure. Recently, more research has focused on the effects of armed conflict on land systems, but still little is known about the processes and outcomes of such events. Here we use the case of Syria and Iraq and the seizure of land by the Islamic State (IS) since 2014 as an example of armed conflict, where we investigate the effects on agricultural land use. We apply a reproducible approach using 250 m satellite-based time-series data to quantify the areas under cultivation from 2000 to 2015. Despite a common belief about widespread land abandonment in areas under conflict, results point to multiple trajectories regarding cropland cultivation in the IS seized area: (1) expansion of cropland to formerly un-cultivated areas, (2) cropland abandonment, and (3) decrease of high-intensity cropland. Our study highlights the need to understand these diverse conflict-related and context-dependent changes to the land system.

1. Introduction

Changes to land systems over time can be caused by slow changes (e.g. urbanization or economic growth) or drastic shocks, such as sudden socio-economic, environmental (Sekizawa *et al* 2015, Hostert *et al* 2011), and political changes (Baumann *et al* 2011), or armed conflicts (Baumann *et al* 2014, Baumann and Kuemmerle 2016). Studies of armed conflicts have shown widespread land use changes through displacement and land abandonment, in some cases causing a reduction of cultivated land and increases in natural vegetation (Stevens *et al* 2011, Gorsevski *et al* 2012, Eklund *et al* 2015). For example, high farmland abandonment rates have been observed in the conflict areas of the 1991–1994 Nagorno-Karabakh conflict between Armenia and Azerbaijan (Baumann *et al*

(2014). Similar to severe droughts, conflicts have been shown to have negative effects on vegetation productivity over time, thus potentially leading to land degradation (de Beurs and Henebry 2008). Biodiversity loss can be another effect of armed conflict, where protected areas are no longer guarded and sometimes become part of the conflict area (Hanson *et al* 2009), or become affected by refugee influx (Sato *et al* 2000). Despite the increased research focus on conflict and land systems, little is yet understood about this topic (Baumann and Kuemmerle 2016). There is thus no comprehensive theory or framework to describe the diverse impacts of armed conflicts on land systems. On one hand, armed conflict may lead to deaths and outmigration from conflict areas, causing agricultural production decline and land abandonment (Baumann *et al* 2014, Eklund *et al* 2015). On the other hand,

insurgents may use agriculture as an income source and therefore try to increase agricultural production (Jaafar and Woertz 2016). Civilians may also expand agricultural production due to cuts in a stable food supply (Alix-Garcia *et al* 2013). Which land use outcome(s) an armed conflict leads to depends on, for example, the nature of the conflict and the socio-economic and biophysical conditions.

The invasion of Iraq in 2003 and its subsequent instability, the current conflict in Syria, and the emergence of the Islamic State (IS, also known as ISIS, ISIL, Da'esh) have caused large-scale displacement of people and widespread destruction of infrastructure and society at large. By January 2015 the Syrian conflict had led to an estimated 12 million refugees (Fanack Chronicle 2016), and there were 3.2 million internally displaced people in Iraq by October 2015 (UNOCHA 2015). The immediate impact of armed conflict and population exodus should presumably have a visible impact on agricultural production and land use. However, due to the general lack of statistical data in unsafe conflict zones, the state, rate, and extent of agricultural land use change in Syria and Iraq are unknown. This information is however crucial to ensure that aid and food security programs are based on quantitative numbers rather than narratives alone.

Satellite remote sensing plays a fundamental role in monitoring land use change (Hostert *et al* 2011, Witmer 2008, Witmer 2015), particularly in unsafe areas. Classification of land use with a dense time-series of satellite imagery has proved to be suitable to map agricultural dynamics and land use change including agricultural abandonment, which is one potential outcome of population displacement due to armed conflicts (Estel *et al* 2015, Estel *et al* 2016, Alcantara *et al* 2012, Alcantara *et al* 2013).

In this study, we aim to contribute an improved understanding of the effects of armed conflict on how land is managed and used. This is done through the following specific objectives:

1. map the extent of cropland in Syria and Iraq for the period 2000 to 2015 at an annual scale,
2. identify major changes in land use in Iraq and Syria,
3. analyze and discuss land use changes in the areas under influence by the Islamic State (IS).

2. Data and methods

2.1. Study area

The area covering Iraq and Syria (28.35–37.84°N, 35.29–49.14°E) is characterized by mountains in the northeast, plains in the southwest, and large expanses of arid desert in the south. The largest rivers are the Tigris and the Euphrates, both originating in eastern Turkey, running in separate streams through Syria and Iraq, and re-joining in southern Iraq before they enter

the Gulf (Held and Cotter 2006). Precipitation is higher in the mountain areas, where the mean annual precipitation exceeds 400 mm. In the flat desert areas, the mean annual precipitation ranges between 100 and 400 mm. Agriculture in the region includes dryland farming of cereal crops, such as wheat and barley (Eklund *et al* 2015), as well as irrigated cash crops, such as tobacco, cotton, and pistachio nuts (Mourad and Berndtsson 2012, Beaumont 1996).

Both Syria and Iraq, but also neighboring countries, experienced a severe drought during the 2007–2009 seasons, which caused widespread socio-economic distress (Trigo *et al* 2010, Eklund and Seaquist 2015, Kelley *et al* 2015, UNDP 2010). Reported socioeconomic effects of drought both in Iraq and Syria included rural to urban migration, loss of livelihoods, and crop failures. Some would argue that the Syrian uprising in 2011 was partly caused by the drought (Gleick 2014, Kelley *et al* 2015). In March 2011, pro-democracy protests erupted in Syria as revolutions spread across the Arab world. By December 2011, the United Nations warned that Syria was on the verge of civil war (Bakri 2011), with different factions fighting each other and government forces. The IS gained a lot of media attention in June 2014 when it declared the establishment of a 'caliphate' (an area under Islamic political rule) and started seizing large areas of territory in Syria and Iraq (Jabareen 2015). Since then, the IS has carried out genocidal attacks against Yazidis and other minority groups in Iraq and Syria, taken responsibility for several terrorist attacks around the world, and both gained and lost land to other groups and governments.

The IS considers itself a state and that includes responsibility to provide, for example, health care, power supply, and food, to its population. Hansen-Lewis and Shapiro (2015) found the IS economy to be based on unsustainable economic activities such as illicit oil trade, sale of cultural artifacts, ransoms, extortions, and taxation. According to a New York Times article, 30% of IS's taxation revenue comes from agriculture (Almukhtar 2016). Food silos and other infrastructure have been regarded as strategic assets, exemplified by IS's confiscation of governmental grain storage facilities in Northern Iraq in 2014 (Fick 2014). Grains have also been confiscated from farmers who fled the area, as well as lands and livestock. Recently, there have been studies on agricultural transformation due to armed conflict in Syria and Iraq (Jaafar *et al* 2015, Jaafar and Woertz 2016). In Syria, irrigated agricultural production has been reported to have dropped by between 15% and 30% in the Orontes river basin from 2000 to 2013 (Jaafar *et al* 2015). Another study though observed stability in agricultural production in areas controlled by the IS, despite expected decreases in cultivated lands due to population outflow from conflict areas (Jaafar and Woertz 2016). Thus, the implications of land seizure by the IS in parts of Syria and Iraq regarding agricultural production remain unclear.

Table 1. IS zones definitions from the ISW.

| | |
|-----------------|--|
| IS control zone | An area where the IS exerts physical/psychological pressure to assure that individuals/groups respond as directed. |
| IS attack zone | An area where the IS conducts offensive maneuvers. |
| IS support zone | An area free of significant action against the IS and which permits logistics and administrative support of the IS's forces. |

2.2. Land control data

A map of the spatial extent of the IS from the Institute for the Study of War (ISW) was georeferenced and digitized (Institute for the Study of War 2015). The map represents the situation in June 2015 and includes support zones, control zones, and attack zones (explained in table 1, shown in figure 1). The control and support zones are areas that are more stable than the attack zones that changes from day to day. Therefore, only control and support zones were used in this analysis, hereafter referred to as IS zones.

2.3. Satellite imagery

For this work we used the MODerate resolution Imaging Spectroradiometer (MODIS) product MOD09 collection 6, available at 250 m spatial and 8 d temporal resolution (Vermote *et al* 2011). Measurements of 38 representative fields, identified using Google Earth imagery, showed an average field size of 125 000 m², which makes the MODIS pixel size of 250 by 250 m (62 500 m²) appropriate for this study. We calculated the normalized difference vegetation index (NDVI) from red and near infrared bands, and ran a 30 d moving average to smooth the time-series and remove holes and pixels contaminated by clouds. NDVI senses the green part of the vegetation, and has been widely used as a proxy for vegetation productivity, or as a measure of the land surface's greenness (Solano *et al* 2010).

2.4. Land use classification

To distinguish cropland from other land uses, we applied an approach making use of the distinct phenology of different vegetation types (Pittman *et al* 2010, Eklund *et al* 2015). The plant's phenological behavior is characterized by seasonal changes in net primary productivity, which can be captured by satellite time-series with a high temporal resolution (Pittman *et al* 2010). Four classes with a distinct seasonal pattern were identified (figure 2): (0) bare soil, fallow land, and artificial surfaces, (1) cropland with one harvest period (single cropped), (2) cropland with two harvest periods (double cropped), and (3) natural vegetation (grassland, woodland) and orchards (see SI available at stacks.iop.org/ERL/12/054004/mmedia).

Training data samples were collected for four years of the whole period: 2003, 2007, 2013, and 2015. The training data were collected manually on a pixel basis

and were based on a combination of Landsat imagery and the MODIS NDVI season for each year. The Landsat data (Thematic Mapper (TM), Enhanced Thematic Mapper (ETM) and Operational Land Imager (OLI); a full list of images is provided in SI) were used as georeferenced RGB images to visually identify land use classes at a spatial resolution of 30 m, which were then compared with the underlying seasonality seen in the MODIS NDVI time-series of the same year. For training purposes, only clear samples covering at least one MODIS pixel (250 × 250 m) were selected.

A total of 1573 training points covering four years (table 2) were used to build a random forest model that was then applied to all years (2000–2015).

A random forest is a non-parametric machine learning technique (Belgiu and Drăguț 2016, Gislason *et al* 2006) that has nowadays replaced most traditional classification methods (Löw *et al* 2015, Estel *et al* 2015). We ran a random forest parametrization in GRASS GIS v. 7.0 (Neteler *et al* 2012) with a setting of 500 trees. Several MODIS-based input images describing the seasonality of the dominant vegetation within a pixel were used as input to train the model. The variables used in the model included the smoothed NDVI in 8 d time-steps (1–46 for each year) and several statistical metrics that were calculated based on these 46 images. After a test run with 64 input images for each year, only the best 15 variables were selected (see SI for the included variables). The importance of the variables explaining the training samples varied, with the growing period from March to May (images 12–17) and the (second) harvest period in September (images 32, 33) showing high significance. Moreover, statistical metrics describing the dynamics of these periods (the ratio between the median and maximum NDVI, and the maximum NDVI) showed the highest significance. The model was then run for each year (2000–2015) using the same set of input variables for the given year.

2.5. Collection of reference data and accuracy assessment

A random forest has a built in cross-validation accuracy assessment by only using 66% of the training data to build the model, whereas the remaining samples are used for validation (Breiman 2001). Here our model achieved an overall accuracy of 91%. However, this validation is biased on the overall manual setting of the training points, which is also based on the availability of Landsat imagery. We thus applied an additional independent validation by setting 800 random training points (roughly 200 points per class) for the year 2014, with a minimum distance of 500 m between the validation points to avoid potential spatial autocorrelation (Kraemer *et al* 2015). The land use of these points was again determined by means of visual assessment of Landsat and NDVI seasonality. Accuracy assessment results

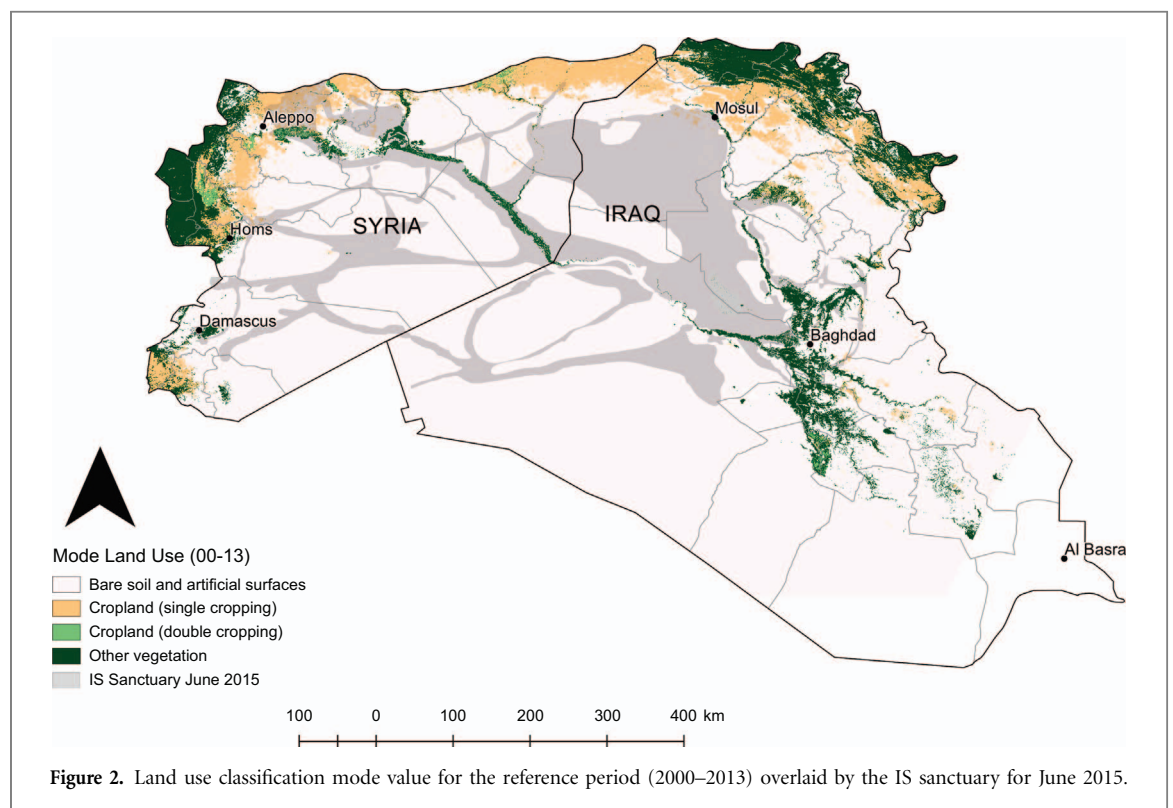
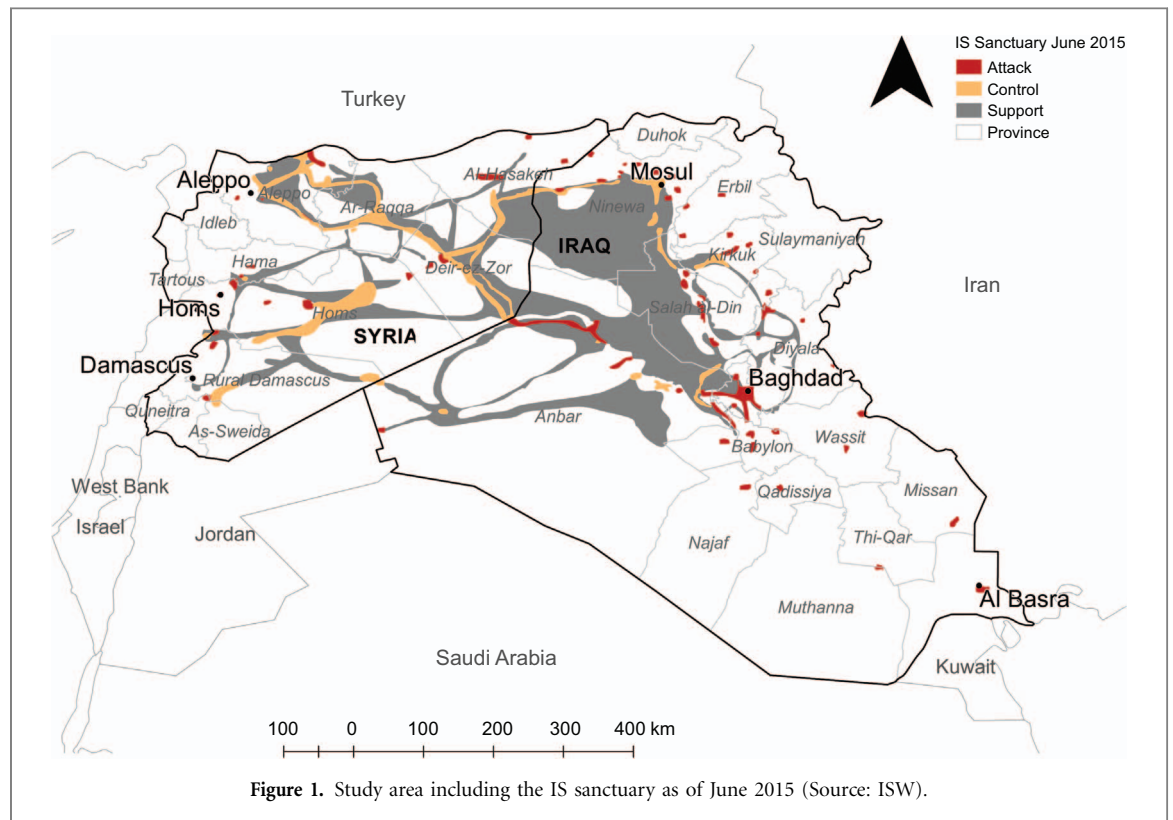
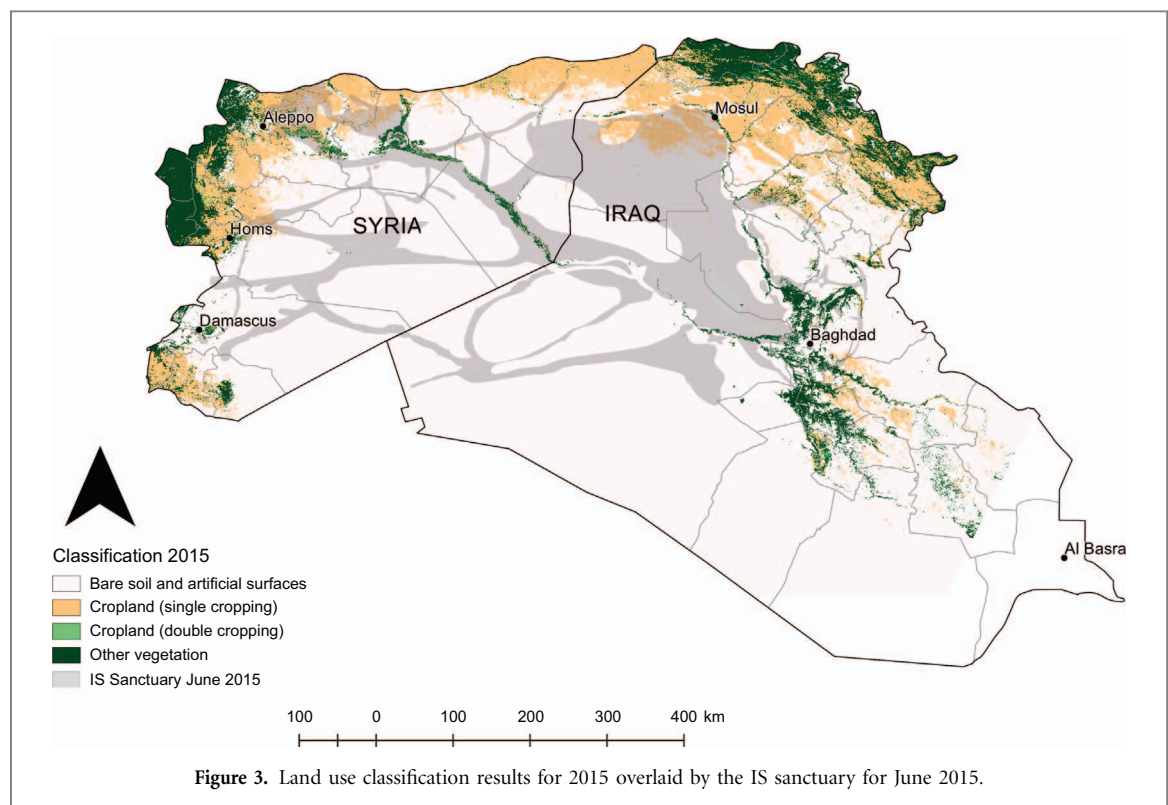


Table 2. Training data collected per class and year.

| Year/Class | Bare soil/fallow | Cropland (single) | Cropland (double) | Natural vegetation | Total |
|--------------|------------------|-------------------|-------------------|--------------------|-------------|
| 2003 | 97 | 169 | 41 | 75 | 382 |
| 2007 | 118 | 173 | 45 | 65 | 401 |
| 2013 | 83 | 118 | 36 | 46 | 283 |
| 2015 | 126 | 213 | 32 | 136 | 507 |
| Total | 424 | 673 | 154 | 322 | 1573 |



were used to calculate adjusted area estimates for each class and year (Congalton 1991, Olofsson *et al* 2014, Olofsson *et al* 2013).

2.6. Land use changes

To track the dynamics of cropland from 2000 to 2015 we summarized the cropland extent (both single and double cropping) inside the IS zones. We also generated 200 random points inside the IS zones and calculated average rainfall during the months of April–June to understand the cropland dynamics' relation to precipitation. Precipitation data came from the Tropical Rainfall Measuring Mission (TRMM, v. 3B42) (Huffman *et al* 2007) dataset, which has a spatial resolution of 0.25° and a temporal coverage of 1998–2015. In order to understand the effect of precipitation on cropland extent we correlated the yearly spring precipitation with the cropland extent using the non-parametric Spearman rank correlation.

We use a long-term reference period based on the years 2000–2013 for comparison with the land use situation in 2015. To get an understanding of the most common land use for every pixel, the mode (most common) class value was calculated for 2000–2013. Furthermore, to identify changes that occurred after 2013, we included information about the particular land use class for 2013 in our analysis. The 2000–2013 mode class and the 2013 class were then compared with the class for 2015. By doing so, we can compare both long-term (reference period versus 2015) and short-term (2013 versus 2015) changes and identify areas that, for example, had been cropland for most of

the reference period, as well as in 2013, but had seen a change in 2015. We focused on changes from and to cropland (double and single cropping).

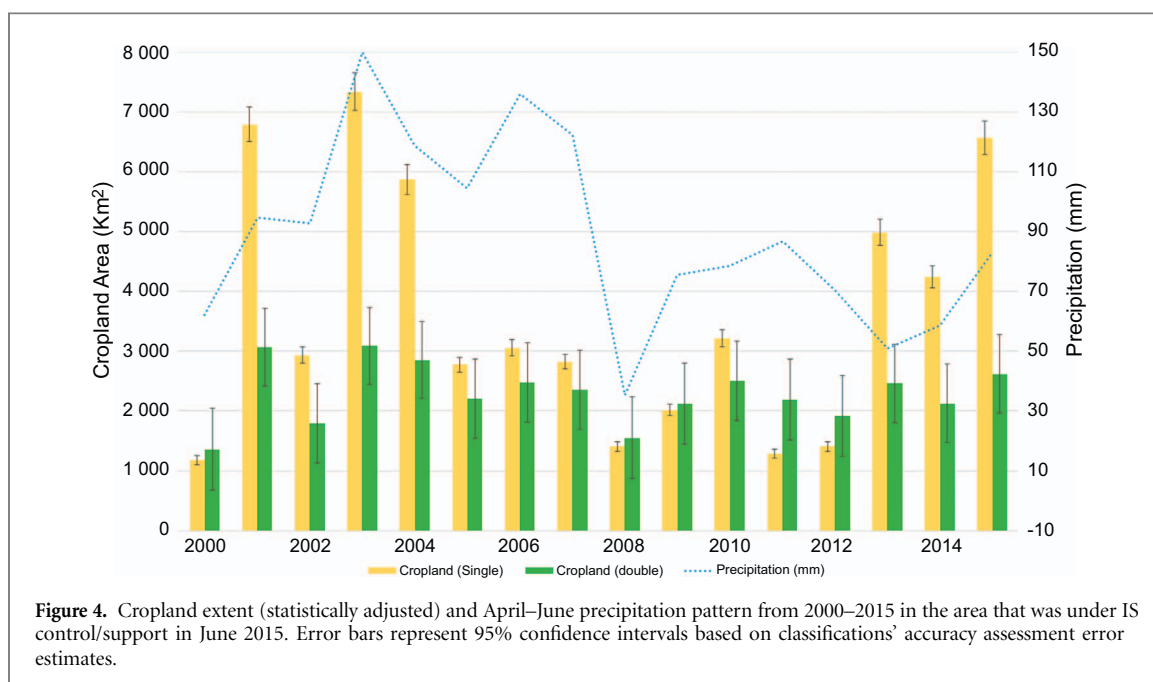
3. Results

3.1. Land use in the study area during the 2000–2013 reference period

About 26 000 (± 1200) km² (5%) of the study area had single cropped cropland as the mode land use class between 2000 and 2013 (figure 2). An additional 14 000 (± 3400) km² (2%) were used for double cropped agriculture. Almost 38000 (± 1500) km² (7%) were classified as other vegetation, and 490 000 (± 3400) km² (86%) were classified as bare soil, fallow, or artificial areas most of the years. For the area that was later occupied by the IS in 2015, 2100 (± 100) km² (2%) were classified as single cropped cropland, 2000 (± 700) km² (2%) were classified as double cropped cropland, 3800 (± 200) km² (4%) were classified as other vegetation, and 101 000 (± 700) km² (93%) were classified as bare soil, fallow, or artificial areas.

3.2. Land use in IS zones in 2015

The land controlled or influenced by the IS in June 2015 covered an area of nearly 110 000 km². About 6600 (± 300) km² (6%) of the IS zones were classified as single cropped cropland in 2015, and 2600 (± 700) km² (2%) were classified as double cropped (figure 3). Almost 4000 (± 200) km² (4%) were classified as other vegetation, and 95 000 (± 700) km² (86%) were classified as bare soil, fallow, or artificial areas. The classification also showed that 15% of Iraq's total



cropland and 34% of Syria's total cropland were inside the IS zones in June 2015.

3.3. Cropland dynamics in IS areas 2000–2015

The extent of cultivated land inside the IS area in 2015 fluctuated throughout the study period. The year 2003 saw the largest cropland extent with over 7300 (± 300) km² of single cropped land (figure 4). Between 2005 and 2012, the cultivated area declined to between 1400 (± 80) km² (2008) and 3200 (± 140) km² (2010). The severe 2008 drought reduced the amount of active cropland in the study area, but in the years after 2008 there was a slight increase in cultivated areas that coincided with better precipitation conditions. In 2011, we observed another drop in cultivated areas, followed by an increase in 2013 and in subsequent years, despite less rainfall. Cropland with two harvest periods (double cropping) generally covered a smaller area than single cropped land. Although a significant and moderate correlation between rainfall and cropland extents was found ($\rho = 0.42$, $p = 0.1$), precipitation alone can only explain approximately 20% of the variations in cropland extents. This is not surprising, as economic and political incentives as well as irrigation play an important role in this region. For example, the cropland areas in 2015 was 88% larger than what could be explained by rainfall variations, which is the largest such deviation over the period.

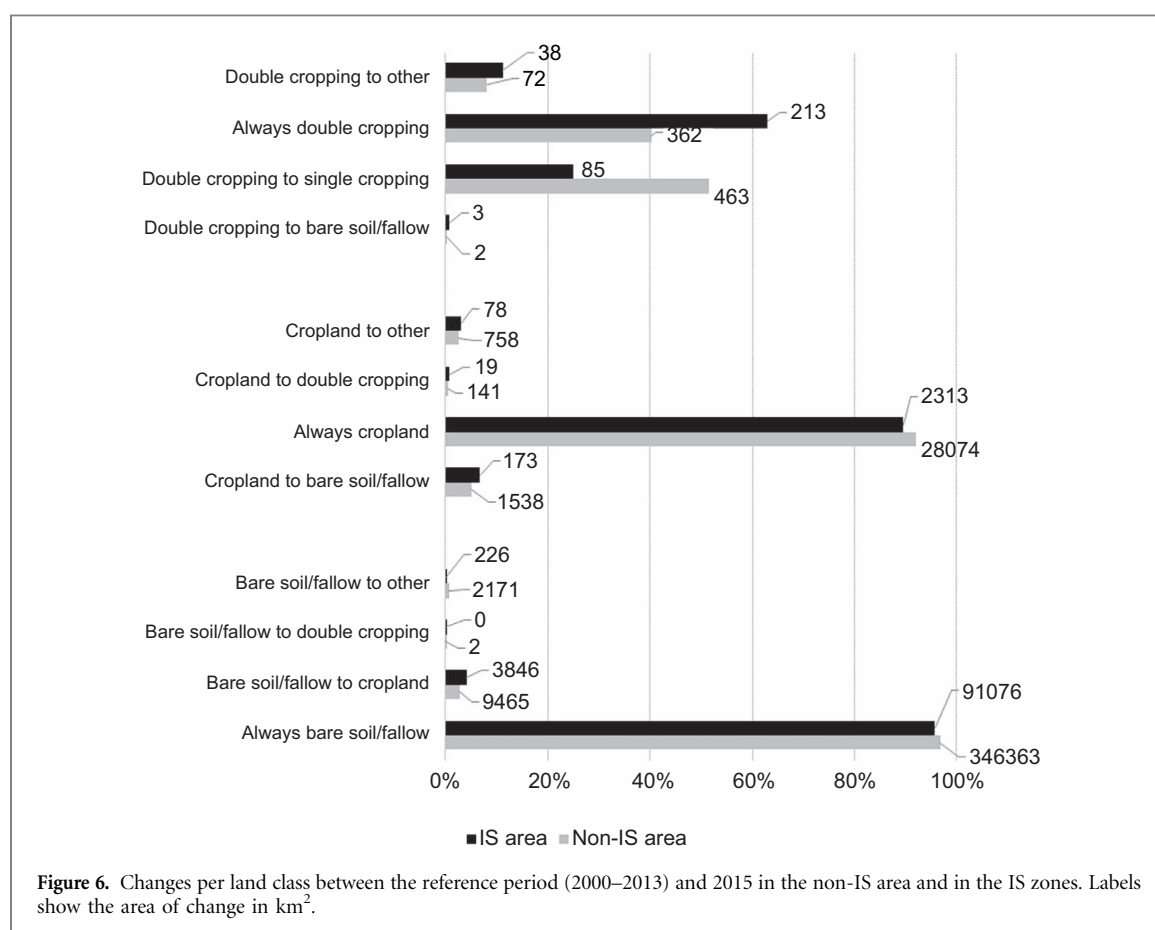
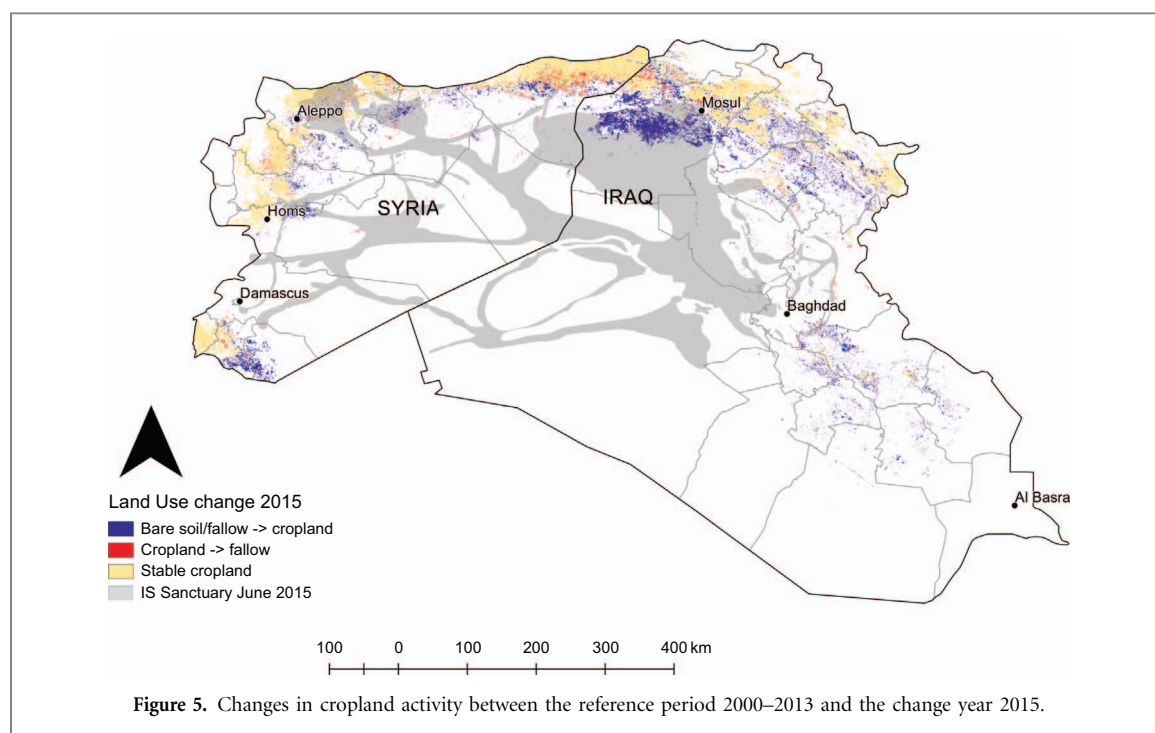
3.4. Land use changes between 2000–2013 and 2015

The land use change map showed that the most widespread change within the IS zones was a change from fallow/bare soil to cropland (cropland expansion) (4.7% of the total IS area), most of it located in the Ninewa governorate in northern Iraq (figure 5).

To put the changes in relation to the extent of land use classes in the IS area we compared changes to the extent of cropland and fallow/bare soil during the reference period (2000–2013). As much as 96% of the land that was fallow/bare soil during the reference period had remained fallow/bare soil in 2015, while 4% had been converted to croplands (figure 6). Of the reference period cropland (single cropped), 7% had been converted to fallow/bare soil, while 90% had remained stable. In Iraq and Syria (excluding the IS zone), 5% had been converted to fallow/bare soil, and 92% had remained stable. A pronounced change inside the IS area was recorded in high-intensity cropland, where 25% of all cropland with two harvest periods had been changed to single cropped in 2015. In the non-IS area, however, 52% of the double cropped lands had changed to single cropped, indicating that the ability to maintain high-intensity farming were higher in the IS zones.

3.5. Accuracy assessment

The overall accuracy for the 2014 classification was 80%, with a producer accuracy of 95% and a user accuracy of 66% for single cropland (table 3). This means that 95% of the single cropland identified in the validation data also was classified as cropland (single) in the classification, but that only 66% of the classified cropland (single) actually was cropland according to the validation data. We therefore had some over-classification issues with single cropland and other vegetation. High-intensity cropland with two harvests showed a producer accuracy of 74%, and a user accuracy of 92%. This caused lower confidence in area estimates, as the total area of double cropped land was small. Other classes' accuracies were above 75%, and the kappa value was 0.73.



4. Discussion

Our results show that in June 2015 the IS was in control of an area that included 15% of Iraq's total cropland and one third of Syria's. This means a change in land control that might have an effect on who manages the lands and how. Our results support three

major short-term changes to the land use in Iraq and Syria (both inside and outside the IS zones) since the large-scale land seizure of the IS: cropland expansion, cropland decrease (abandonment), and reduction of cropland intensity.

Looking at the land use change maps we see an overall increase in cropland area where almost 5% of

Table 3. Results from the accuracy assessment for 2014.

| Class | Producer Accuracy | User Accuracy |
|---------------------|-------------------|---------------|
| 0—Bare soil | 75% | 99% |
| 1—Cropland (single) | 95% | 66% |
| 2—Cropland (double) | 74% | 92% |
| 3—Other vegetation | 76% | 77% |
| Overall accuracy | 80% | |
| Kappa | 0.73 | |

the total IS area had seen a conversion from fallow/bare soil to cropland in 2015. This change was particularly widespread in the northern part of the Ninewa governorate in Iraq, in areas both inside and outside the IS zones. Furthermore, the area used for single cropland in the IS zones in 2015 were three times as much as the reference classification for the same area. A *fatwa* (religious edict) was issued by the IS in December 2014 stating that the agricultural lands of people who have fled can be seized as war booty, indicating that abandoned lands can be reclaimed and cultivated under IS control (al-Tamimi 2015). Furthermore, the IS has been reported to force landowners to keep cultivating the land in order to control food production (Jaafar and Woertz 2016, Regional Food Security Analysis Network (RFSAN) 2016). In addition to using abandoned lands, we also find that fallow lands have been taken into cultivation again.

Considering that over 15 million people have been forced to leave their homes in Syria and Iraq due to the conflict, abandonment of land was expected. We found signs of land abandonment in the IS zones where 7% of what had been cropland during the reference period (2000–2013) had changed to fallow/bare soil in 2015. This is only slightly more than land abandonment outside the IS zones, in which only 5% of the cropland was converted to fallow/bare soil. A special report from Reuters stated that many farmers in the IS zones of Iraq had not planted any seeds for the 2015 season due to land access problems, fertilizer and fuel shortages, and uncertainty of getting their crop bought by the new ‘government’ (Fick 2015). Cropland turned fallow inside the IS zones did not show any particular spatial concentration, indicating that these changes were happening at a smaller scale.

A change in cropland intensity was seen inside the IS zones, where 25% of the double cropping area had only been harvested once in 2015. Important to note here is the small extent of double cropped area inside the IS zones, so the change in absolute terms is not that remarkable. Furthermore, the non-IS zones saw a much larger relative change, where 52% of the high-intensity cropland changed from having two to only one harvest. This indicates that farmers in both Iraq and Syria were having problems maintaining high-intensity agriculture, but that farmers inside the IS zones were maintaining high-intensity agriculture to a wider extent.

The accuracy assessment showed a relatively high overall accuracy (80%), a value which is in line with similar studies using comparable data sources (see Hostert *et al* (2011), Estel *et al* (2015) and Löw *et al* (2015)). Some caution should be taken as we have identified some over-estimations of single cropland and other vegetation, and under-estimations of bare soil, double cropland, and other vegetation. By calculating adjusted area estimates, these uncertainties are represented in the reported results; however, it is difficult to identify the exact location of errors in the classification maps.

Whether the identified changes will be permanent or temporary cannot be determined at this point, but it will be a topic of our future investigations as the situation progresses, since the constructed model can easily be applied for monitoring the coming years. Other cases of conflicts and socio-economic shocks have shown to cause regime shifts in land use trajectories, such as reduced intensity in land use (Hostert *et al* 2011). If the armed conflict situation continues, we may see short-ages in agricultural inputs, such as seeds and fertilizers (reported by Dahan and Barrington (2016)) which will reduce the ability of farmers to maintain high-intensity agriculture. On the other hand, as the results of this article show that 63% of the high-intensity agriculture was maintained in IS areas (compared to 40% in non-IS areas), there may already be informal trade routes that have secured access to agricultural inputs in certain areas. Migration of skilled agricultural workers may lead to changes in land management, potentially affecting the productivity of land.

Changes to land use in armed conflict contexts can be caused by a variety of different factors, both related to, and independent of, conflict. While the availability of water from rainfall directly affects the ability to grow crops, we found that rainfall alone could not explain the fluctuations in cropland extent in the IS zones. Instead, we need to look at other incentives for land use changes, such as agricultural policies or market demand. As an example, the government of Iraq forced farmers to increase the cropland extent in order to compensate for the government’s inability to import food and fertilizer, during a period of international trade sanctions in the 1990s (Gibson *et al* 2012). Syria has, on the other hand, had a recent history of market-oriented agricultural policies, where government incentives supported certain strategic crops and heavy irrigation (Eklund and Thompson, [submitted](#)). The complex relationships between conflict, economy, migration, and land use needs further investigation to give a better understanding of the causal mechanisms that drive land use change in conflict contexts.

Food security in Iraq and Syria have, according to, e.g. the Food and Agriculture Organisation (FAO) (2014), FAO (2016), World Food Programme (WFP) (2016), and Whole of Syria (2016), been negatively affected by limited access to infrastructure, increased

food prices, lowered livelihood activities, as well as reductions in planted and harvested areas. FAO (2016) reported that an estimated 9.4 million Syrians were in need of food assistance in June 2016, due to displacement and problematic food access conditions. Our results show that the food security situation in the two countries is compromised by access and affordability issues, rather than by a reduction in agricultural land use. However, even though our results show an increase in low-intensity croplands in 2015, we do not know who is cultivating the land, or where the produced crops end up. Jaafar and Woertz (2016) reported sustained production in IS controlled areas and highlighted the fact that agriculture had become an important revenue for the IS, but also that there is much uncertainty about where the production goes. Estimates on cultivated areas in Syria, which show opposite results to ours, are generally based on government reports, field observations, group interviews, and questionnaires, which are described as 'indicative' rather than absolute (FAO 2016). A satellite-based classification of land use could greatly improve those assessments to gain more reliable numbers.

5. Conclusions

This paper provides insights into how the emergence of the IS has affected agricultural activity in Syria and Iraq. A major result is a cropland expansion in 2015 in areas that have been fallow for a longer period. In addition to these increases in cropland, we also find the opposite development—areas where cropland has turned fallow, and a shift from high- to low-intensity farming. This means that the emergence of the IS and the related violence have reshaped the agricultural landscape of Iraq and Syria in some areas, but that low-intensity agriculture has generally been maintained and even expanded in some places. Interestingly, even high-intensity farming seems to have been better maintained inside the IS zones than in the rest of Iraq and Syria. These findings raise questions about the strategic use of agriculture in conflicts, for example as a source of revenues, sustenance for fighters, or to appease the local population. Further research should also look at the prospects for long-term sustainability of agricultural production in conflict areas.

This research highlights the fact that the effects of armed conflict on land use are not unidirectional, but that changes are heterogeneous and dependent on local contexts. This demonstrates the complexity of the population-land nexus in conflict situations and shows the need for a better understanding of the contexts in which these changes are happening. Further research on the topic of conflict and land systems should focus on developing a framework for understanding which socioeconomic, environmental, and conflict-related factors play a role in creating certain land change outcomes.

Acknowledgments

This research was conducted through the Middle East in the Contemporary World (MECW) project funded by the Swedish Research Council. Martin Brandt is funded by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement (project BICSA number 656564). Alexander Prishchepov acknowledges Openlab initiative at Kazan Federal University. The authors thank Darcy Thompson for helpful feedback throughout the writing process.

References

- Alcantara C, Kuemmerle T, Baumann M, Bragina E V, Griffiths P, Hostert P, Knorn J, Müller D, Prishchepov A V and Schierhorn F 2013 Mapping the extent of abandoned farmland in Central and Eastern Europe using MODIS time series satellite data *Environ. Res. Lett.* **8** 035035
- Alcantara C, Kuemmerle T, Prishchepov A V and Radeloff V C 2012 Mapping abandoned agriculture with multi-temporal MODIS satellite data *Remote Sens. Environ.* **124** 334–47
- Alix-Garcia J, Bartlett A and Saah D 2013 The landscape of conflict: IDPs, aid and land-use change in Darfur *J. Econ. Geogr.* **13** 589–617
- Almukhtar S 2016 Life under the Islamic State fines, taxes punishments *The New York Times* (www.nytimes.com/interactive/2016/05/26/world/middleeast/isis-taxes-fines-revenue.html?_r=0)
- Al-Tamimi A 2015 Archive of Islamic State administrative documents (<http://www.aymennjawad.org/2015/01/archive-of-islamic-state-administrative-documents>)
- Bakri N 2011 UN says action needed to prevent civil war in Syria *New York Times* (www.nytimes.com/2011/12/03/world/middleeast/un-says-action-needed-to-prevent-civil-war-in-syria.html)
- Baumann M and Kuemmerle T 2016 The impacts of warfare and armed conflict on land systems *J. Land Use Sci.* **11** 672–88
- Baumann M, Kuemmerle T, Elbakidze M, Ozdogan M, Radeloff V C, Keuler N S, Prishchepov A V, Kruhlov I and Hostert P 2011 Patterns and drivers of post-socialist farmland abandonment in Western Ukraine *Land Use Policy* **28** 552–62
- Baumann M, Radeloff V C, Avedian V and Kuemmerle T 2014 Land-use change in the Caucasus during and after the Nagorno-Karabakh conflict *Reg. Environ. Change* **15** 1703–16
- Beaumont P 1996 Agricultural and environmental changes in the upper Euphrates catchment of Turkey and Syria and their political and economic implications *Appl. Geogr.* **16** 137–57
- Belgiu M and Drăguț L 2016 Random forest in remote sensing: a review of applications and future directions *ISPRS J. Photogramm.* **114** 24–31
- Breiman L 2001 Random forests *Mach. Learn.* **45** 5–32
- Congalton R G 1991 A review of assessing the accuracy of classifications of remotely sensed data *Remote Sens. Environ.* **37** 35–46
- Dahan M E and Barrington L 2016 Exclusive: Battered by war Syria's wheat crop halved this year to new low (www.reuters.com/article/us-syria-wheat-idUSKCN11P1HG)
- de Beurs K M and Henebry G M 2008 War, drought, and phenology: changes in the land surface phenology of Afghanistan since 1982 *J. Land Use Sci.* **3** 95–111
- Eklund L, Persson A and Pilesjö P 2015 Cropland changes in times of conflict, reconstruction, and economic development in Iraqi Kurdistan *Ambio* **45** 78–88

- Eklund L and Seaquist J 2015 Meteorological, agricultural and socioeconomic drought in the Duhok Governorate, Iraqi Kurdistan *Nat. Hazards* **76** 421–41
- Eklund L and Thompson D Differences in resource management affects drought vulnerability across the borders between Iraq Syria and Turkey *Ecol. Soc.* submitted
- Estel S, Kuemmerle T, Alcántara C, Levers C, Prishchepov A and Hostert P 2015 Mapping farmland abandonment and reclamation across Europe using MODIS NDVI time series *Remote Sens. Environ.* **163** 312–25
- Estel S, Kuemmerle T, Levers C, Baumann M and Hostert P 2016 Mapping cropland-use intensity across Europe using MODIS NDVI time series *Environ. Res. Lett.* **11** 024015
- Fanack Chronicle 2016 Refugees of the war in Syria (<https://chronicle.fanack.com/specials/refugees/refugees-war-syria/>)
- Fick M 2014 Special report: Islamic State uses grain to tighten grip in Iraq *Reuters* (www.reuters.com/article/us-mideast-crisis-wheat-idUSKCN0HP12J20140930)
- Fick M 2015 Special report: For Islamic State wheat season sows seeds of discontent *Reuters* (www.reuters.com/article/us-mideast-crisis-planting-specialreport-idUSKBN0KT0W420150120)
- Food and Agriculture Organization of the United Nations (FAO) 2014 Serious food security concerns following escalation of conflict *Global Information Early Warning System on Food Agriculture Special Alert (GIEWS)* (www.fao.org/3/a-i3898e.pdf)
- Food and Agriculture Organization of the United Nations (FAO) 2016 Special report: FAO/WFP crop food security assessment mission to the Syrian Arab republic (http://documents.wfp.org/stellent/groups/public/documents/ena/wfp288721.pdf?_ga=1.91557983.43142726.1484666891)
- Gibson G R, Campbell J B and Wynne R H 2012 Three decades of war and food insecurity in Iraq *Photogramm. Eng. Remote Sens.* **78** 885–95
- Gislason P O, Benediktsson J A and Sveinsson J R 2006 Random forests for land cover classification *Pattern Recogn. Lett.* **27** 294–300
- Gleick P H 2014 Water, drought, climate change, and conflict in Syria *Weather Clim. Soc.* **6** 331–40
- Gorsevski V, Kasischke E, Dempewolf J, Loboda T and Grossmann F 2012 Analysis of the impacts of armed conflict on the Eastern Afromontane forest region on the South Sudan–Uganda border using multitemporal landsat imagery *Remote Sens. Environ.* **118** 10–20
- Hansen-Lewis J and Shapiro J N 2015 Understanding the Daesh economy *Perspect. Terrorism* **9** 142–55
- Hanson T, Brooks T M, Da Fonseca G A, Hoffmann M, Lamoreux J F, Machlis G, Mittermeier C G, Mittermeier R A and Pilgrim J D 2009 Warfare in biodiversity hotspots *Conserv. Biol.* **23** 578–87
- Held C C and Cotter J V 2006 *Middle East Patterns: Places, Peoples, and Politics* (Boulder, CO: Westview Press)
- Hostert P, Kuemmerle T, Prishchepov A, Sieber A, Lambin E F and Radeloff V C 2011 Rapid land use change after socio-economic disturbances: the collapse of the Soviet Union versus Chernobyl *Environ. Res. Lett.* **6** 045201
- Huffman G J, Bolvin D T, Nelkin E J, Wolff D B, Adler R F, Gu G, Hong Y, Bowman K P and Stocker E F 2007 The TRMM multisatellite precipitation analysis (TMPA): Quasi-global, multiyear, combined-sensor precipitation estimates at fine scales *J. Hydrometeorol.* **8** 38–55
- Institute for the Study of War 2015 *ISIS Sanctuary Map June 19, 2015* (www.understandingwar.org/map/isis-sanctuary-june-19-2015)
- Jaafar H H and Woertz E 2016 Agriculture as a funding source of ISIS: a GIS and remote sensing analysis *Food Policy* **64** 14–25
- Jaafar H H, Zurayk R, King C, Ahmad F and Al-outa R 2015 Impact of the Syrian conflict on irrigated agriculture in the Orontes Basin *Int. J. Water Resour. Dev.* **31** 436–49
- Jabareen Y 2015 The emerging Islamic State: Terror, territoriality, and the agenda of social transformation *Geoforum* **58** 51–5
- Kelley C P, Mohtadi S, Cane M A, Seager R and Kushnir Y 2015 Climate change in the Fertile Crescent and implications of the recent Syrian drought *Proc. Natl Acad. Sci.* **112** 3241–6
- Kraemer R, Prishchepov A V, Müller D, Kuemmerle T, Radeloff V C, Dara A, Terekhov A and Frühauf M 2015 Long-term agricultural land-cover change and potential for cropland expansion in the former Virgin Lands area of Kazakhstan *Environ. Res. Lett.* **10** 054012
- Löw F, Fliemann E, Abdullaev I, Conrad C and Lamers J P 2015 Mapping abandoned agricultural land in Kyzyl-Orda, Kazakhstan using satellite remote sensing *Appl. Geogr.* **62** 377–90
- Mourad K A and Berndtsson R 2012 Analysis of agricultural production in Syria from a virtual water flow perspective *J. Agric. Sci. Appl.* **1** 60–6
- Neteler M, Bowman M H, Landa M and Metz M 2012 GRASS GIS: a multi-purpose open source GIS *Environ. Modell. Softw.* **31** 124–30
- Olofsson P, Foody G M, Herold M, Stehman S V, Woodcock C E and Wulder M A 2014 Good practices for estimating area and assessing accuracy of land change *Remote Sens. Environ.* **148** 42–57
- Olofsson P, Foody G M, Stehman S V and Woodcock C E 2013 Making better use of accuracy data in land change studies: estimating accuracy and area and quantifying uncertainty using stratified estimation *Remote Sens. Environ.* **129** 122–31
- Pittman K, Hansen M C, Becker-reshef I, Potapov P V and Justice C O 2010 Estimating global cropland extent with multi-year MODIS data *Remote Sens.* **2** 1844–63
- Regional Food Security Analysis Network (RFSAN) 2016 The impact of ISIS on Iraq's agricultural sector situation overview (http://reliefweb.int/sites/reliefweb.int/files/resources/07122016_IRQ_Iraq_Agri_Brefing_V2.pdf)
- Sato H, Yasui K and Byamana K 2000 Follow-up survey of environmental impacts of the Rwandan refugees on eastern DR Congo *AMBIO J. Hum. Environ.* **29** 122–3
- Sekizawa R, Ichii K and Kondo M 2015 Satellite-based detection of evacuation-induced land cover changes following the Fukushima Daiichi nuclear disaster *Remote Sens. Lett.* **6** 824–33
- Solano R, Didan K, Jacobsson A and Huete A 2010 MODIS vegetation index user's guide MOD13 series vegetation index phenology lab (https://vip.arizona.edu/documents/MODIS/MODIS_VI_UserGuide_01_2012.pdf)
- Stevens K, Campbell L, Urquhart G, Kramer D and Qi J 2011 Examining complexities of forest cover change during armed conflict on Nicaragua's Atlantic coast *Biodivers. Conserv.* **20** 2597–613
- Trigo R M, Gouveia C M and Barriopedro D 2010 The intense 2007–2009 drought in the Fertile Crescent: impacts and associated atmospheric circulation *Agr. Forest Meteorol.* **150** 1245–57
- UNDP 2010 Drought impact assessment recovery mitigation framework regional project design in Kurdistan Region (KR) (www.undp.org/content/dam/rbas/report/Drought.pdf)
- UNOCHA 2015 Humanitarian needs overview Iraq (<http://reliefweb.int/report/iraq/iraq-humanitarian-needs-overview-2016-november-2015>)
- Vermote E, Kotchenova S and Ray J 2011 MODIS surface reflectance user's guide *MODIS Land Surface Reflectance Science Computing Facility version 13* (http://modis-sr.ltdri.org/guide/MOD09_UserGuide_v1_3.pdf)
- Whole of Syria (WOS) 2016 Food security sector Whole of Syria Mid-Year Review 2016 (http://reliefweb.int/sites/reliefweb.int/files/resources/fss_wos_myrt_2016.pdf)
- Witmer F D W 2008 Detecting war-induced abandoned agricultural land in northeast Bosnia using multispectral, multitemporal Landsat TM imagery *Int. J. Remote Sens.* **29** 3805–31
- Witmer F D W 2015 Remote sensing of violent conflict: eyes from above *Int. J. Remote Sens.* **36** 2326–52
- World Food Program (WFP) 2016 Syria January 2016—Worsening food security conditions in besieged areas (<http://reliefweb.int/sites/reliefweb.int/files/resources/wfp281528.pdf>)